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Land Building Models: Uncertainty in and Sensitivity to Input Parameters

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PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to document a detailed analysis of land building spreadsheet models applied to estimate the net benefits from proposed river diversions. Many of the issues with the key input parameters for the spreadsheet models reviewed in this document will be faced by more complex two- and three-dimensional models when they are applied. The CHETN starts with an overview of the various models that are being applied for land building in coastal Louisiana. The sensitivity of land building estimates to the specification of various key input parameters is analyzed and discussed, highlighting issues associated with those parameters.

INTRODUCTION: Coastal Louisiana has lost over 1.2 million acres of land since 1932, and land loss continues at a rate of over 15,000 acres per year. Water and sediment diversions have been proposed to mitigate land loss and rebuild land in the Mississippi delta. Numerous questions exist regarding the efficacy of diversions for building land and quantifying changes in both the receiving area and river. Freshwater flow diversions can offer significant mineral sediment and nutrient inputs to marshes that result in both inorganic and organic accumulation of soil. However, the capability to estimate land gain is limited.

Several land building models have recently been developed and applied in south Louisiana. Boustany (2007) introduced a screening level model for assessing both the sediment and the nutrient benefit of flow diversions over longtime scales. This model has been applied to screen Coastal Wetland Planning, Protection, and Restoration Act (CWPPRA) project alternatives. The Boustany model calculates the annual land gain from sediments and nutrients separately and adds these values to the existing area, which is adjusted each year by a constant annual land loss value. Nutrient benefits are based on the potential of the diversion to introduce nutrients to support wetland vegetation. The total acres created from nutrients are calculated by multiplying the land area that can be supported with the diversion nutrient load by the land loss rate. This formulation allows nutrients to freely construct land if the diversion is capable of supplying more nutrients than is required by the receiving area wetlands.

The Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) Program (Kim et al. 2008) introduced a land building model that simulates the evolution of a prograding fan-shaped delta advancing into open water. This model is an extension of a tool developed for managing the disposal of mine tailings in water bodies (Parker et al. 1998). The model was calibrated and verified against the observed evolution of the Wax Lake Delta on the Atchafalaya River. The CLEAR model does not explicitly account for the nutrient contribution, and its formulation would only be applicable for diversions into open water bodies.

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The Louisiana Coastal Protection and Restoration Program (LACPR) required a tool to evaluate the land building potential of diversions that could account for both the nutrient and sediment benefits of the flow diversions and compare alternatives. While the Boustany model was capable of assessing relative benefits of various diversion locations, LACPR required a model with greater temporal resolution to analyze the effects of diversion structure type, operational regimes, and hydrologic variability. McKay et al. (2010) adapted the Boustany (2007) model to include daily variation in sediment processes in order to optimize diversion structure design and operation. The approach to sediment retention was updated to calculate sediment retention based on wetland geometry, sediment properties, and flow hydrodynamics at the site. The approach taken by Boustany (2007) was to apply retention factors estimated for other sites or to use professional judgment. The McKay et al. (2010) model incorporates sediment retention calculations and adds intra-annual temporal variability in hydrologic and sediment inputs. This model, referred to as the Sediment And Nutrient Diversion (SAND) model, also slightly modified the nutrient benefit calculations from Boustany.

The SAND model has been further modified to include a time-stepping simulation with the associated temporal variability in model parameters, specification of multiple land loss rates to accommodate various forms of land loss, organic accretion based on available nitrogen, marsh processing of excess nitrogen, and accommodation of benefits associated with mechanical marsh creation efforts. The new model is referred to as SAND2, and the only documentation is an internal report that has not been approved for distribution. The new model framework provides greater flexibility to incorporate spatial and temporal variability. However, the greatest difference in terms of model results is a new handling of the nutrient contribution. Elements of the SAND and SAND2 models and implications on benefit calculations will be discussed further in subsequent sections of this CHETN.

OVERVIEW OF MODEL INPUTS, ASSUMPTIONS, AND FORMULATIONS: The analysis presented in this report is limited to the Boustany, SAND, and SAND2 models. An overview of the assumptions and formulations for each model is presented in this section. All of the land building models reviewed are fundamentally based on the following:

1) Inorganic benefits of flow diversion from the addition of sediment.
2) Organic benefits of flow diversion due to plant growth, mortality, and burial stimulated by addition of the limiting nutrients.
3) Land loss rates applied to account for land loss due to background system processes such as marsh nutrient cycling, net tidal and groundwater inputs, sea level rise, wave action, compaction, subsidence, etc.

The models apply these processes to assess Future With Project (FWP) and Future Without Project (FWOP) conditions for alternative comparison.

Boustany Model. The Boustany (2007) model was developed to assess the feasibility of river diversions and screen diversion alternatives under the CWPPRA. The model is a spreadsheet application that considers both the sediment and nutrient contribution to land building. The model represents the receiving area as a single cell with uniform depth and utilizes an annual time-step to provide quick estimates of the land building potential of diversions. Model inputs are summarized in Table 1.

Table 1. Boustany Model Inputs
Average annual diversion flow rate, Q_{div}
Total suspended sediment (TSS) concentration from river source, C_{sed}
Nutrient concentration from river source, C_{nut}
Area of land in project receiving area, A
Percent land loss in project area each year, δ
Average water depth in receiving area, H
Bulk density of land in receiving area, ρ_{bd}
Percent of TSS retained in receiving area, R_{sed}
Plant productivity rate, P_r
Percent of nutrients retained in system that goes toward plant productivity, R_{nut}
Percent of plant biomass containing nutrients, γ_{TNP}

The Boustany model quantifies the benefit from flow diversions in terms of marsh area. The marsh area is computed at each annual time-step as

$$A_{i+1} = A_i + A_{sed} + A_{nut} - A_i\delta \tag{1}$$

where A_i is land area at time i; A_{sed} is the area of land created by sediment delivered from flow diversion; A_{nut} is the land area benefit from the addition of nutrients by the flow diversion; and δ is the fraction of land loss each year (entered into the model as a percent). The sediment benefit is calculated as

$$A_{sed} = \frac{Q_{s,net}dt}{H\rho_{bd}} \tag{2}$$

where dt is the time-step and

$$Q_{s,net} = Q_{div}C_{sed}R_{sed} \,. \tag{3}$$

The formulation for area of land created assumes that all sediment diverted and retained in the project area creates sub-aerial acres of land. That is, there is no subaqueous volume of sediment that may only be acting to make open water shallower or settling in existing wetland areas.

Because most Louisiana marshes are nutrient limited, Boustany proposes that the concentration of nitrogen and phosphorous be used to calculate the nutrient benefit. The nutrient input promotes plant production which contributes an organic fraction to wetland soil formation. The model computes the total nutrient mass loading required to support each acre of wetland as

$$\zeta = P_r\gamma_{TNP} \,. \tag{4}$$

The total load of nutrients available from the flow diversion is calculated as

$$Q_{nut} = Q_{div} C_{nut} R_{nut} . \tag{5}$$

The total potential land area that can be supported by the diversion nutrient load is then

$$A_{pot,nut} = \frac{Q_{nut} dt}{\zeta} . \tag{6}$$

The nutrient benefit is calculated by multiplying the percent land loss each year by the land area that can be supported by the nutrient load from the flow diversion:

$$A_{nut} = A_{pot,nut} \delta . \tag{7}$$

Note that if the $A_{pot,nut}$ is greater than the acres of land in the receiving area, the acres due to nutrient introduction can actually exceed the acres of land lost. The concept that nutrient load can build new land, rather than preserve existing land, is a matter of debate amongst wetland experts. As will be discussed later in this text, each model treats this process differently.

SAND. The SAND model is an extension of the Boustany model that was developed to allow for the consideration of hydrologic variability and assessment of different diversion operation alternatives. The primary adaptations to the Boustany model include the implementation of a daily time-step (versus annual time-step for the Boustany model); calculation of sediment input from diversion based on a sediment rating curve; calculation of sediment retention based on multiple sediment classes and user-defined sediment processes (settling) for each class and daily diversion flow; calculation of bulk density based on receiving area depth; and a modification to the calculation of benefit from nutrient input. The SAND model also has a Monte Carlo simulation technique for stochastic analysis.

The SAND model represents the receiving area as a single cell of defined area with uniform depth. The SAND model quantifies the benefit from flow diversions in terms of marsh area consistent with Equations (1) – (7). Therefore, similar to the Boustany model, the calculation of land created assumes that all sediment diverted and retained in the project area creates sub-aerial acres of land, and the land is considered built when the bottom elevation is equal to mean sea level. The model adaptations incorporated in the SAND model required input parameter changes and additions, which are summarized in Table 2.

The implementation of a daily time-step allows for the input of a representative diversion hydrograph instead of an average annual flow rate through the diversion. This allows the modeler to investigate different operational alternatives. The model also includes an input river hydrograph, that when taken with the diversion hydrograph, allows for evaluation of various structural alternatives. The inclusion of the river hydrograph also allows for a daily variation in sediment input from the river which is calculated from a sediment rating curve defined by the user. A fixed concentration can also be specified, consistent with the Boustany model. In fact, every capability of the Boustany model is retained, and the user has the option to use the simpler inputs. For example, if the user defines the retention rate (instead of using the model to calculate it based on hydrodynamic and sediment settling processes) and provides a constant concentration input, then the model results will be equivalent to the Boustany model.

Table 2. Additional or Changed Model Inputs (from Boustany to SAND)	
ERDC-SAND Input	**Comment**
River Hydrograph	New input, used in computation of suspended sediment concentration
Diversion Hydrograph	Replaces Average annual diversion flow rate, Q_{div}
Sediment Rating Curve Coefficient (*a*) and Exponent (*b*)	Used with the river hydrograph to compute total suspended sediment (TSS) concentration from river source, C_{sed}
Area of water in project receiving area, A_w	New input, used in sediment retention calculation
Average flow width of receiving area, *B*	New input, used in sediment retention calculation
Roughness height, z_0	New input, used in sediment retention calculation
Reference height, z_a	New input, used in sediment retention calculation
Maximum tidal velocity, U_{max}	New input, used in sediment retention calculation
Fall velocity (W_s) and fraction (*f*) for fine sand, silt, clay, and floc sediments	New input, used in sediment retention calculation
Land loss rate (specified as area per year) in project area, δ	Changed from Boustany which specifies a percent land loss each year

A major advancement implemented in the SAND model is the option to calculate sediment retention based on wetland geometry, sediment properties, and flows at the site. The Boustany model required the user to assign retention factors estimated for other sites or based on the distance of diversion from main river channel and depth of receiving water. Several of the new inputs in Table 2 are related to the sediment retention calculations. Details on the sediment retention calculations are provided in McKay et al. (2010).

The Boustany model requires the user to specify a bulk density that is applied to calculate the area of land created based on the sediment input (Equation 2). The SAND model includes an option to calculate the bulk density based on the average depth and wetland type of the receiving area. The calculation is based on the assumption that the bulk density of marsh sediment is dependent on the depth below the marsh surface. The density is assumed constant throughout a 50-cm surface layer but then increases with depth at a rate of 0.6 g/cm^3/m due to consolidation. The resulting average bulk density is calculated as

$$\rho_{bd,avg} = \frac{H\rho_{bd,surface} + 0.5(H - H_{surface})^2 \dfrac{\partial \rho_{bd}}{\partial H}}{H} \tag{8}$$

where $\rho_{bd,surface}$ = 0.1 g/cm^3 for fresh marsh types and $\rho_{bd,surface}$ =0.2 g/cm^3 for brackish and salt marsh types; $H_{surface}$ = 0.5 m, and $\partial\rho_{bd}/\partial H$ = 0.6 g/cm^3/m.

Finally, the SAND model slightly modifies the nutrient benefit calculation by computing land loss at a constant rate as opposed to a fixed, user-specified percentage each year. Except for this modification, the nutrient benefit in the version of the SAND model that was made available for this review is consistent the Boustany model. However, it should be noted that the documentation provided in McKay et al. (2010) provides an additional modification which limits the nutrient benefit such that it cannot exceed the acres lost. Therefore, in this case, the SAND model produces a more conservative estimate of land building compared to the Boustany model.

SAND2. The SAND model was further modified to include a time-stepping simulation that allows for various forms of land loss, marsh processing of excess nitrogen, organic accretion based on available nitrogen, and mechanical marsh creation. This version of the model is referred to as the SAND2 model in this report. Both the Boustany and SAND models represented the receiving area as a single cell with uniform depth. The SAND2 model divides the receiving area into 100 uniform longitudinal cells (100 × 1) and calculates marsh properties at each cell. The updated scheme allows for distributed sediment settling. Similar to SAND, the SAND2 model assumes a constant initial depth over the entire domain. Depth calculations are then performed by the model for each cell based on sedimentation and primary production.

The SAND2 model increases the computational requirements such that a strictly Excel spreadsheet calculation is no longer suitable. The new model maintains the Excel interface, but model calculations are conducted in Visual Basic for Applications (VBA), which is a built-in function of Microsoft Excel that allows the user to compute multiple iterations. The SAND2 model must be *run* in order to modify results based on altered inputs.

The SAND2 model calculates the benefit due to sediment input consistent with Equations (1) – (3) and therefore has the same inherent assumptions related to these input parameters as the Boustany and SAND models. Specifically, despite the multi-cell structure of SAND2, all sediment that is deposited in the domain is used in the final land building calculation. Internal to the model, each cell is identified as land or water. However, the reported acreage benefit is not based on the number of land cells. Rather, all deposited sediment is used in a single volumetric calculation (Equation 2). Therefore, the total area of cells designated as land, which is calculated in the model and used for sediment and nutrient retention calculations, is not part of the output file and differs from the reported value of land created.

The SAND2 nutrient benefit calculation is significantly different from the other two models. In the SAND2 model simulations, the nutrient benefit is computed based on an approximate nitrogen budget that is developed to assess the fate of diversion loaded nitrogen. The budget accounts for direct burial in sediment, denitrification, plant uptake, and export. The plant uptake portion of the model is the source of nutrient benefit, while the burial and denitrification components reduce the amount of nitrogen available for plant uptake. The SAND2 model assumes that existing nutrient processes are accounted for through the land loss rate, and the nitrogen mass balance is only applied to the most seaward land cell and all subsequent non-land cells. From the first land cell onward, the mass of nitrogen available is determined based on the four processes and transported to the adjacent cell as

$$N_{Exp\ j+1} = N_{Inp,j-1} - N_{Bur,j} - N_{Denit,j} - N_{Uptake,j} \qquad (9)$$

where N_{exp} is the nitrogen exported to the next cell; N_{inp} is the nitrogen input from the previous cell; N_{Bur} is the nitrogen buried; N_{Denit} is the denitrified nitrogen; N_{uptake} is the nitrogen taken up by vegetation; and *j* is cell location.

Mass loading of nitrogen to the wetland is consistent with the other models and is based on the concentration of total nitrogen in the source water and the diversion flow rate (Equation 5). However, in the Boustany and SAND models, the nitrogen concentration is specified as a single mean annual value while the SAND2 model allows for the specification of nitrogen source

concentrations by month. Concentration specification by month is a more realistic representation as nitrogen concentrations in source waters are seasonal due to a variety of drivers such as changes in watershed loading throughout the year and the capacity of source waters to process nitrogen. The SAND2 model assumes nitrogen is buried in a given cell at the rate of clay retention and is calculated as

$$N_{Bur,j} = N_{Inp,j-1} R_{clay} \tag{10}$$

where R_{clay} is the percent of clay retained in cell j.

The rate of denitrification (D) is a user-defined input and should be based on reported values from literature sources. N_{Denit} is calculated as

$$N_{Denit} = DBdx \tag{11}$$

where B is the average flow width of receiving area (which is equivalent to cell width) and dx is the project area cell length in the longitudinal direction. The benefits of nitrogen addition are the stimulation of vegetation growth which contributes to the organic fraction of wetland soil formation. The nitrogen uptake and associated production of plant biomass is estimated from primary production (P_r) which is given in mass per unit area

$$M_{bio} = P_r Bdx\,. \tag{12}$$

The nutrient uptake required to produce the biomass is

$$N_{uptake} = M_{bio}\gamma_{TN}\,. \tag{13}$$

Primary production is highly variable through the growing season with more biomass produced in warm months than in cold months. The SAND2 model, therefore, applies monthly estimates of primary production for uptake and accretion calculations as opposed to the Boustany and SAND models which only allow for a single input value. There is a great deal of uncertainty in this parameter as values in the literature vary significantly depending upon marsh type, collection technique, and whether above and below ground components are considered. The nutrient benefit is then calculated as

$$A_{nut} = \frac{M_{bio}}{H\rho_{bd}}\,. \tag{14}$$

The background land loss rate is also a parameter in all the models. The Boustany model specifies land loss as a fixed percentage each year. The SAND and SAND2 models employ a user-specified land loss as a linear or nonlinear rate. The SAND2 model has the capability to specify differing loss rates for Future With Project (FWP) and Future Without Project (FWOP) conditions, and land loss rates can be temporally varying, changed at defined critical values of either area or time.

MODEL APPLICATION: The model review presented in this report will be accomplished through analysis of an application for a hypothetical Mississippi River diversion project with a maximum flow rate of 35,000 cfs. The models are applied to estimate wetland acreages throughout the life of the project and driven with a 25-year river hydrograph developed from Mississippi River data. Inputs to the models are kept as consistent as possible to allow for an inter-comparison of model results. For example, an average annual diversion flow was computed from the diversion hydrograph input to the SAND model, and that average flow was used to drive the Boustany model. The historic Relative Sea Level Rise (RSLR) FWP and FWOP alternatives were simulated with both the Boustany and the SAND models with inputs consistent with the SAND2 application. The Boustany and SAND model inputs are summarized in Table 3. The SAND2 inputs are summarized in Table 4. The computed benefits from all models are summarized in Table 5. The results in Table 5 serve as the base simulation against which subsequent simulations for sensitivity purposes are compared.

Table 3. Boustany and SAND Model Inputs for the Base Simulation

Input	Boustany	SAND
Daily Average Diversion Flow Rate (cfs)	3,940	Input Hydrograph
Initial Land Area, *A* (ac)	50,000	50,000
Project Area, A_p (ac)	NA	100,000
Average Water Depth, *Hwater* (ft)	2.07	2
Average Water Width, *B* (ft)	NA	25,000
Length of project, *L* (ft)	NA	Calculated
Maximum Tidal Velocity, $U_{tide,max}$ (ft/s)	NA	1
Roughness Height, z_o (ft)	NA	0.0006562
Total suspended sediment (TSS) concentration from river source, C_{sed} (mg/L)	100	Calculated
Sediment Rating of River, Coefficient	NA	3.205E-07
Sediment Rating of River, Exponent	NA	2
Size fraction by mass, *f,* of fine sand	NA	0.01
Size fraction by mass, *f,* of silt	NA	0.63
Size fraction by mass, *f,* of clay	NA	0.36
Size fraction by mass, *f,* of floc	NA	0.3
Percent of TSS retained in receiving area, R_{sed}	82	Calculated
Source Concentration of Nutrients (mg/L)	2.023	2.023
Plant Productivity Rate (g/m^{2}y)	4150	4150
Percent of Plant Biomass made of nutrients	1.25	1.25
Percent of nutrients retained in system that goes toward plant productivity, R_{nut}	40	40
Bulk Density, ρ_{bd} (g/cm^3)	0.208	0.208
FWP Land Change Rate, δ	0.55%	275 ac/y
*NA - Not applicable for this model		

Table 4. SAND2 Model Inputs for the Medium Diversion at White Ditch Project Base Simulation	
Initial Land Area, *A* (ac)	50,000
Project Area, A_p (ac)	100,000
Average Water Depth, *Hwater* (ft)	2
Average Water Width, *B* (ft)	25,000
Length of project, *L* (ft)	175,000
Maximum Tidal Velocity, $U_{tide,max}$ (ft/s)	1
Roughness Height, z_o (ft)	0.0006562
Sediment Rating of River, Coefficient	3.205E-07
Sediment Rating of River, Exponent	2
Size fraction by mass, *f,* of fine sand	0.01
Size fraction by mass, *f,* of silt	0.63
Size fraction by mass, *f,* of clay	0.36
Size fraction by mass, *f,* of floc	0.3
Source Concentration of Nutrients (mg/L)	Variable by month, 1.638 to 2.778
Plant Productivity Rate (g/m^2y)	Variable by month, 3735 to 4357.5
Percent of Plant Biomass made of nutrients	1.25
Denitrification Rate of the marsh (g/m^2y)	21
Bulk Density, ρ_{bd} (g/cm^3)	0.208
FWP Land Change Rate (ac/y)	275
FWOP Land Change Rate (ac/y)	275

Table 5. Boustany, SAND and SAND2 Model Calculations of Total Project Benefit

	Boustany		SAND		SAND2	
Alternative	**Acres ($x10^3$)**	**Benefit Acres ($x10^3$)**	**Acres ($x10^3$)**	**Benefit Acres ($x10^3$)**	**Acres ($x10^3$)**	**Benefit Acres ($x10^3$)**
FWOP	34		36		36	
FWP	66	32	68	32	72	36

ANALYSIS: The following analysis documents the sensitivity of the models to various key model parameters and provides background on the uncertainty associated with each parameter. The analysis also documents the impact of certain model assumptions. Specifically, the influence of the sediment rating curve, grain size distribution in the diverted flow, bulk density, marsh elevation, depth of the receiving area, specification of project area, land loss rate, and nutrient contribution will be evaluated.

Sediment Rating Curve. Model results are obviously determined by the total mass of sediment supplied from the flow diversion. For instance, in the Boustany model, if the specified suspended sediment concentration is reduced from 100 mg/L, as in the base condition, to 50 mg/L, the total net acres of benefit drop from 33,000 acres to 19,000 acres. Therefore, a 50 percent cut in the suspended sediment reduces the benefit by approximately 42 percent.

The SAND and SAND2 models allow for the total diverted sediment to be calculated based on the river hydrograph and a sediment rating curve in addition to specifying a constant concentration. Rating curves and their development are subject to uncertainty, even when based on a consistent

data set. Figure 1 is a plot of the two rating curves with the same source data. Curve 2 is higher at lower discharges but lower at higher discharges relative to Curve 1. Both the SAND and the SAND2 model were run with both curves. Curve 1 provided higher net benefit (FWP-FWOP) estimates with both models. Applying Curve 2, the SAND model prediction dropped by approximately 4000 acres (~12 percent) and the SAND2 model prediction dropped by approximately 1000 acres (~3 percent).

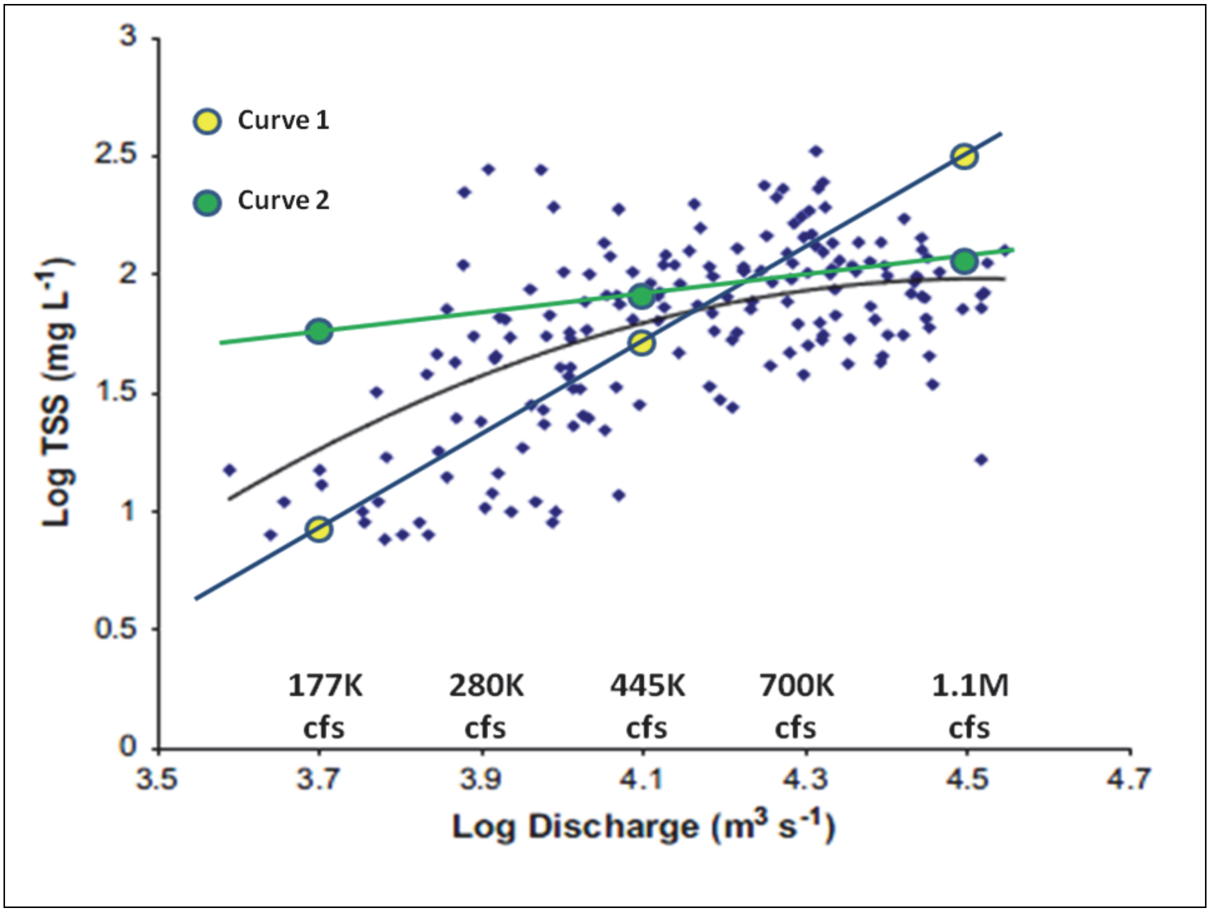

Figure 1. Sediment rating curves.

Grain Size Distribution. Sediment retention in the project area is a function of wetland geometry, sediment properties, and hydrodynamic flows. If the grain size distribution changes in the SAND or SAND2 models, the total sediment retained can change and, thus, so can the benefit calculation. The Boustany model has a user-specified retention rate and does not allow for specification of the sediment grain size distribution and is, thus, insensitive to this parameter. The grain size distribution applied for the base simulation was 1 percent fine sand, 63 percent silt, and 36 percent clay, with a floc fraction of 30 percent. The floc fraction defines the portion of silt and clay mass that is bound as flocs. The SAND and SAND2 model sensitivity to the grain size distribution was assessed by modifying the base simulation sediment distribution from a primarily silty material to a clay material. The grain size distribution for Simulation GSD1 was 1 percent fine sand, 36 percent silt, and 63 percent clay with the floc fraction maintained at 30 percent. The results are summarized in Table 8. The increase in clay material, and corresponding decrease in silt

sediment, results in less material being retained in the receiving area in both the SAND and SAND2 models. The SAND model calculated benefit is reduced by 25 percent while the SAND2 model benefit decreases approximately 10 percent.

Table 8. SAND and SAND2 Model Sensitivity to Grain Size Distribution

		SAND		SAND2	
Sim. No.	Size Fraction	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)
Base	*fsand=0.01* *fsilt=0.63* *fclay=0.36* *ffloc=0.30*	68	32	72	36
GSD1	*fsand=0.01* *fsilt=0.36* *fclay=0.63* *ffloc=0.30*	61	24	68	32
GSD2	*fsand=0.01* *fsilt=0.63* *fclay=0.36* *ffloc=0.80*	74	38	76	40
GSD3	*fsand=0.01* *fsilt=0.36* *fclay=0.63* *ffloc=0.80*	72	36	75	38

There is a great deal of uncertainty in the floc fraction parameter as this is a function of the sediment composition as well as the time histories of factors such as turbulence, salinity, and sediment concentration. The 30 percent floc fraction is likely on the low end of what may be expected, so the sensitivity to this parameter was assessed by increasing the value to 80 percent (Simulations GSD2 and GSD3). Simulation GSD2 is the predominantly silty sediment concentration and is compared to the Base simulation. Simulation GSD3 is predominantly clay and is compared to Simulation GSD1. The results are summarized in Table 8. Increasing the floc fraction results in a greater retention of the clay sediments and the wetland acreage is increased in both the SAND and SAND2 models. Once again, the SAND model is more sensitive to the change in sediment distribution relative to SAND2. Also, because the increase in flocculation results in greater clay material retention, the simulation with a greater fraction of clay sediments is more sensitive to the floc fraction than is a silty material. For the predominantly silty sediment concentration, the wetland acreage benefit increases by 20 percent in the SAND model and 10 percent for SAND2 with an increase in the floc fraction. The simulation with a predominately clay material indicates the benefit calculation increases by 50 percent for SAND and 20 percent for SAND2.

Bulk Density. The importance of bulk density of the receiving wetland determining the acres of wetland created is evident from how it enters into Equation 1 (Boustany, SAND, and SAND2) and Equation 14 (SAND2). However, bulk densities of wetland soils are highly variable and thus subject to a large degree of uncertainty. Wetland soils are typically composed of both mineral and organic sediment. The wet bulk density for pure mineral sediment beds ranges between 1.2 (clays) and 1.8 g/cm^3 (sands). Soils high in organics and air content may have dry bulk densities well

below 1.0 g/cm³. Bulk densities for organic peats are less than 0.09 g/ cm³ for fibric peats but can be greater than 0.2 g/cm³ for sapric peats (Faulkner and Richardson 1989). Bulk density profiles reflect the discontinuous process of mineral sedimentation as seen in Figure 2. Figure 2 plots bulk density with depth in a pair of cores collected from a non-fresh *Spartina alterniflora*-dominated stable marsh site. The profile clearly reflects the dynamic process of mineral sedimentation where bulk density values spike up with the introduction of inorganic sediment. Figure 3 plots the dry bulk density versus the percent organic material for various marsh types based on data from Coast-wide Reference Monitoring System (CRMS) sites in south Louisiana. As expected, as the relative amount of organic material decreases (and therefore the mineral sediment fraction increases), bulk density values increase.

Since the bulk density is a function of the mineral sediment input, the bulk density for wetlands receiving a regular source of inorganic sediment from a river diversion is expected to be higher than wetlands cut off from the river. Figure 4 documents the bulk density for two CRMS sites typical of a wetland isolated from river water and sediment. As documented in Figure 4, the top 24 cm soil dry bulk density ranges from 0.14 to 0.51 g/ cm^3, and the average dry bulk density for the two sites is 0.29 g/ cm^3.

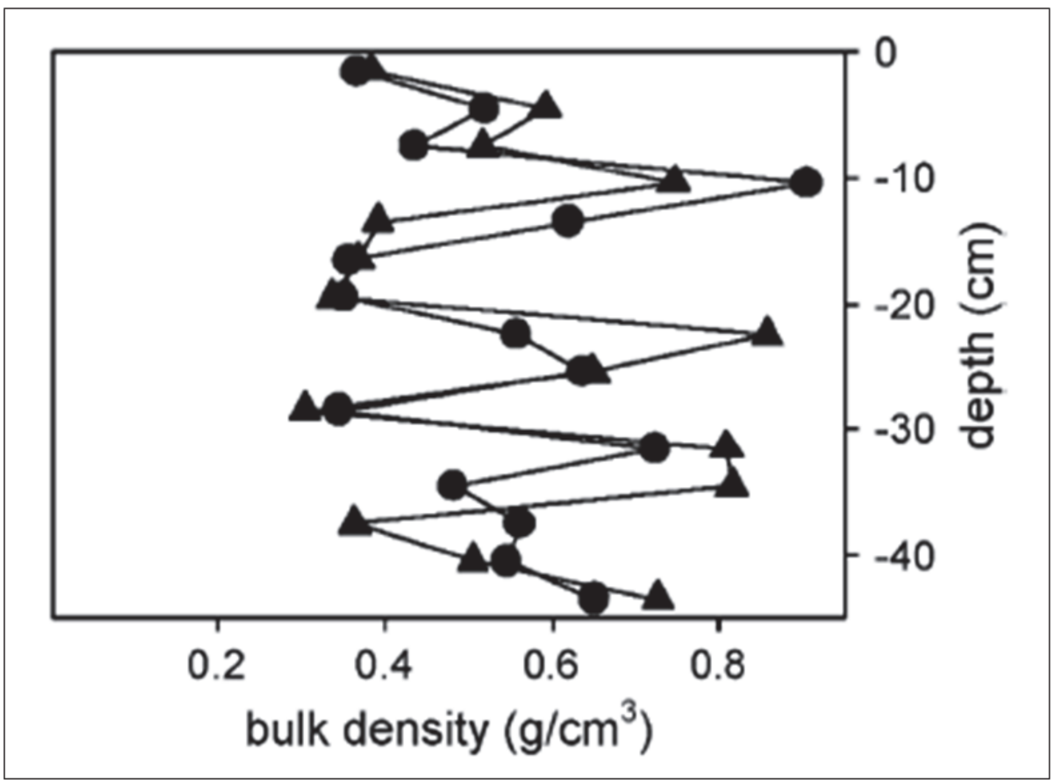

Figure 2. Bulk density profiles with depth in a pair of cores collected from a non-fresh stable site (From Nyman et al. 2006).

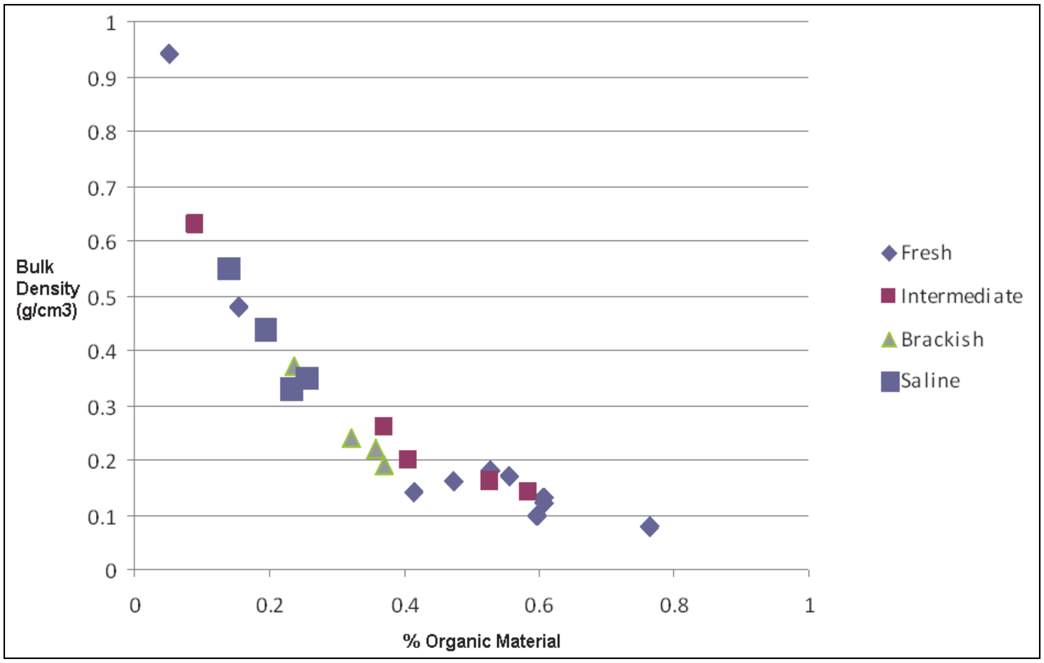

Figure 3. Bulk density versus percent organic material based on data from CRMS sites in various marsh types.

Marsh Elevation: 1.12ft NAVD1988
Bulk Density: 0.150 g cm^{-3}
NRCS Soil Type: Clovelly muck

Depth (cm)	Average Bulk Density g cm^{-3}	Error
0 to 4	0.17	±0.05
4 to 8	0.14	±0.04
8 to 12	0.15	±0.05
12 to 16	0.15	±0.03
16 to 20	0.14	±0.04
20 to 24	0.14	±0.02

Site 1

Marsh Elevation: 1.34ft NAVD1988
Bulk Density: 0.423 g cm^{-3}
NRCS Soil Type: Bellpass muck

Depth (cm)	Average Bulk Density g cm^{-3}	Error
0 to 4	0.37	±0.09
4 to 8	0.46	±0.1
8 to 12	0.51	±0.05
12 to 16	0.34	±0.02
16 to 20	0.38	±0.06
20 to 24	0.5	±0.17

Site 2

Figure 4. Bulk density measurements at two CRMS sites typical of a wetland cut off from river water and sediment.

Bulk density values measured in an active delta may be more representative of a wetland receiving a regular source of sediment. Measurements at Wax Lake Delta indicate that the bulk density of this newly created land is between 0.5 and 0.9 g/cm^3. Based on these measurements, the CLEAR program applied a value of 0.835 g/cm^3 for land building calculations (Visser et al. 2003). The CRMS program has measured bulk density in the Mississippi River delta, and Figure 5 is a plot of CRMS sites near the river source. The dry bulk density at these locations varies from 0.378 to 1.121 g/cm^3. The average bulk density for the top 24 cm of marsh for all the available sites in the delta is 0.775 g/cm^3.

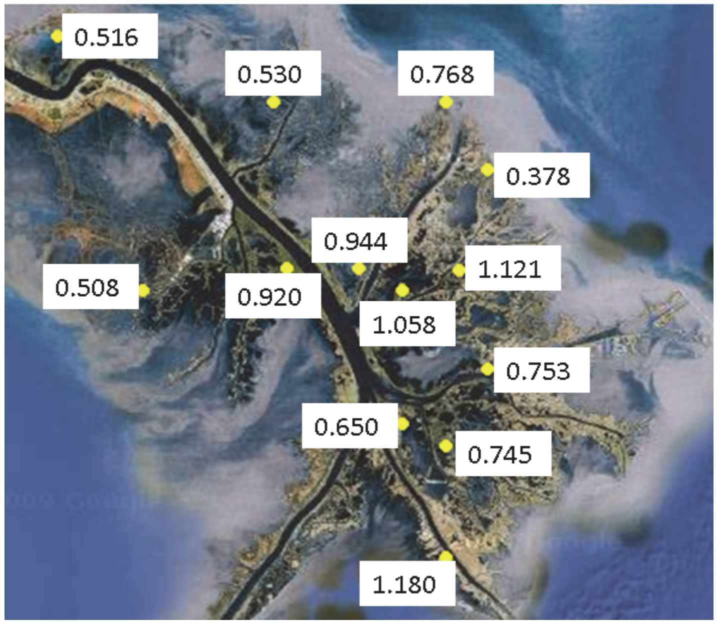

Figure 5. Bulk density values in the Mississippi River active delta. Values are in g/cm^3 and are averages for top 24 cm of marsh surface. Average for all sites is 0.775 g/cm^3.

These data indicate the variability and uncertainty in bulk density of receiving wetlands. For the base case, a bulk density of 0.208 g/cm^3 was applied. This value was calculated from Equation 8. Equation 8 is based on the assumption that the bulk density of marsh sediment is dependent on the salinity regime and the depth below the marsh surface. The user-defined density remains somewhat constant throughout a surface layer (upper 50 cm) but then shows significant consolidation with increasing depth. Equation 8 applies a bulk density value of 0.2 g/cm^3 for the surface layer of brackish/salt marsh and 0.1 g/ cm^3 for fresh marsh. The data presented in this CHETN suggest that Equation 8, as implemented in the SAND and SAND2 models, produces bulk density values at the low end of the expected range. To assess the sensitivity of the model to the bulk density value, simulations were run with all three models with an assigned bulk density of 0.5, 0.7, and 0.9 g/cm^3. The net acres created for these simulations and the base condition simulation (bulk density = 0.208 g/cm^3) are summarized in Table 9. Results indicate that model predictions are sensitive to the bulk density parameter. Benefits are significantly reduced with a bulk density of 0.5 g/cm^3, and model results indicate that after 50 years, with the diversion in place, the wetland acreage is increased by 2,000 acres or fewer from the initial acreage of 50,000 for all three models. For bulk density estimates greater than 0.5 g/cm^3, the models predict that the diversion is essentially able to maintain the original land acreage or experience less than 10 percent land loss. Note that the SAND2 model is generally the most sensitive model as bulk density enters into the calculation of both inorganic (Equation 1) and organic (Equation 14) benefits. It should also be noted that the sensitivity of the models to the specification of bulk density is nonlinear, with the models being much more sensitive to changes when the bulk density values being applied are relatively low.

Table 9. Boustany, SAND and SAND2 Model Sensitivity to Bulk Density							
		Boustany		SAND		SAND2	
Sim.No.	Bulk Density (g/cm^3)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)
Base	0.208	66	32	68	32	72	36
BD1	0.5	51	15	52	15	52	16
BD2	0.7	46	13	48	12	48	12
BD3	0.9	47	10	47	10	45	9

Marsh Elevation. Inherent in the formulation for area of land created in each of the models (Equation 1) is the assumption that land is considered *built* when the bottom elevation is equal to mean sea level. In reality, healthy vegetated marsh typically is at some elevation, on the order of about 1 ft, depending on marsh type. There are two consequences of this assumption: (1) The calculation of the depth dependent bulk density in the SAND model does not account for marsh elevation, and (2) the additional volume of soil to account for elevation above MSL is not accounted for. The assumption is based on the concept that once vegetation becomes established, additional accretion comes from the trapping of suspended sediments during high tides and storm events not accounted for from the diversion. However, the quantification of this is uncertain, and results based on this assumption likely represent an upper bound for land building estimates.

The calculation of bulk density in the SAND and SAND2 models is depth dependant and based on the depth of the receiving basin (Equation 8). However, because marsh elevation is not considered in the base case, calculations from Equation 8 undervalue the bulk density. This concept is illustrated in Figure 6. The example in Figure 9 is for the hypothetical application where the bulk density is calculated based on the input depth of 2 ft and a surface bulk density of 0.2 g/cm^3. Equation 8 provides a value of 0.208 g/cm^3. However, if we assume the marsh has an elevation (η in Figure 6) of 1 ft, the calculated bulk density increases to 0.261 g/cm^3. Changing the bulk density in the SAND2 model to 0.261 g/cm^3 (consistent with the theory behind Equation 8) reduces the diversion land benefit (FWP-FWOP) from 36,000 to 29,000 acres, a 7,000 acre (~20%) reduction. This result further highlights the sensitivity of results to changes in bulk density, particularly when the specified value is relatively low. It should be noted that in practice marsh elevation should always be accounted for in the computation of bulk density.

The land area benefit from the addition of sediment (and nutrients for the SAND2 model, see Equation 13) by the flow diversion is computed by dividing the mass of sediment diverted by a bulk density to get the volume of land and then dividing the volume by a depth (Equation 1). Because the model divides by the receiving area depth, the volume of land required to reach the elevation of a healthy marsh is not accounted for in the base case. Each of the model inputs were modified to account for an additional 1 ft of marsh elevation and simulated. Both the effect on the sediment volume requirement for land building and the effect on the bulk density were considered. The results are summarized in Table 10. Consideration of marsh elevation reduces the land area benefit by greater than 40 percent for all models. It should be noted that the percent change resulting from the consideration of marsh elevation would be less for deeper receiving basins.

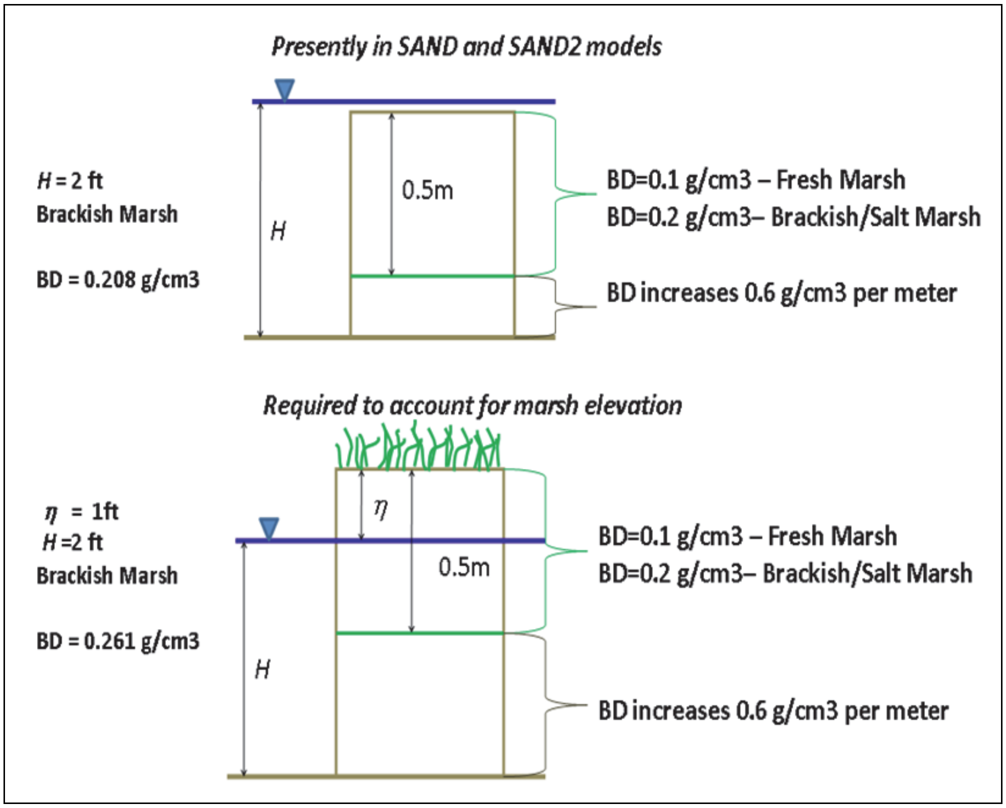

Figure 6. Schematic of calculation of bulk density using Equation 8.

Table 10. Boustany, SAND and SAND2 Model Sensitivity to Consideration of Marsh Elevation of 1 ft

Sim. No.	Bulk Density (g/cm^3)	Boustany		SAND		SAND2	
		FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)
Base	0.208	66	32	68	32	72	36
ME1	0.261	54	18	55	18	56	20

Depth of Water in Receiving Area. From examination of Equation 1 and the discussion on marsh elevation, the importance of the depth of the receiving water in computing the land area benefit is clearly evident. The depth of the receiving area water should be based on best available data. An average depth for the entire receiving area is specified, and a value of 2 ft was used for the hypothetical application. To assess the sensitivity of the models to this parameter, the total average depth for the entire project area was doubled to 4 ft, and two additional simulations were made. To isolate the impact of changing the water depth only, in the first simulation (DEP1) the base condition inputs were kept constant, and only the water depth was changed to 4 ft. For the second simulation (DEP2), in addition to updating the depth, an updated bulk density based on a depth of 4 ft was calculated and applied as input. The results for these simulations are summarized in Table 11. Increasing the depth input reduces the land area benefit by nearly 50 percent for the SAND2 model and about 45 percent for the Boustany and SAND models. When the depth is increased, and the appropriate adjustments to bulk density made, land area benefit is reduced by approximately 67 percent for the SAND2 model and 60 percent for the Boustany and SAND models.

Table 11. Boustany, SAND and SAND2 Model Sensitivity to Water Depth in Receiving Area							
		Boustany		SAND		SAND2	
Sim. No.	Inputs/ Assumptions	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)
Base	H=2 ft ρ_{bd} =0.208 g/cm^3	66	32	68	32	72	36
DEP1	H=4 ft ρ_{bd} =0.208 g/cm^3	53	18	53	18	55	19
DEP2	H=4 ft ρ_{bd} =0.327 g/cm^3	49	13	49	13	49	12

Specification of Project Area. The specification of the project area can also influence the calculation of net benefits as it influences sediment retention calculations and, indirectly, the average depth of the receiving area. The definition of project area limits determines not only the size of the receiving, which enters into the calculation of retention, but also impacts the average depth. If deeper water off the seaward edge of a continuous marsh is included, the average water depth of the receiving area can increase significantly. The sensitivity to the receiving area to depth was documented in a previous section of this CHETN. Simulation PA1 decreases the project area by 25 percent and maintains the other inputs consistent with the base condition to isolate the impact of changing project area. Sediment retention values are summarized in Table 12. Nearly all of the sand, silts, and flocs are retained in the original project area for both the SAND and SAND2 models. The SAND2 model predicts a larger percentage of clay is retained, due to the numerical implementation of time- and space-stepping. When the project area is reduced, the sands and silts are still nearly all retained in the smaller project area. The floc retention rate is reduced by 5-10 percent and the clay retention rate is reduced by more than one-half.

Table 12. SAND and SAND2 Calculated Sediment Retention Values										
Sim. No.	Inputs/ Assumptions	Boustany	SAND				SAND2			
		*R_{total}	R_{sand}	R_{silt}	R_{clay}	R_{floc}	R_{sand}	R_{silt}	R_{clay}	R_{floc}
Base	H=2 ft ρ_{bd} =0.208 g/cm^3 A_p=100,000 ac	82%	100%	100%	0.6%	100%	100%	100%	2.7%	99.2%
PA1	H=2 ft ρ_{bd} =0.208 g/cm^3 A_p=75,000 ac	81%	100%	100%	0.3%	95.0%	100%	98.9%	1.2%	91.3%
*Value is not calculated in the Boustany model. Values here were based on average total retention rate calculated by the SAND model										

The land benefit results are summarized in Table 13. Simulation PA1 results indicate that the land area benefit is reduced, relative to the Base simulation, by nearly 20 percent for the SAND2 model and less than 10 percent for the Boustany and SAND models.

Table 13. Boustany, SAND and SAND2 Model Sensitivity to Specification of Project Area							
		Boustany		SAND		SAND2	
Sim. No.	Inputs/ Assumptions	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)	FWP Acres ($x10^3$)	FWP-FWOP Acres ($x10^3$)
Base	H=2 ft ρ_{bd} =0.208 g/cm^3 A_p=100,000 ac	66	32	68	32	72	36
PA1	H=2 ft ρ_{bd} =0.208 g/cm^3 A_p=50,000 ac	65	31	66	30	65	29

Land Loss Rate. Land loss rates are used to account for land loss due to background system processes such as marsh nutrient cycling, net tidal and groundwater inputs, sea level rise, compaction, subsidence, etc. The loss rate is user-specified and should be based on historical values or historical values adjusted to account for accelerated sea level rise. The sensitivity of each model to the input land loss rate was analyzed by re-simulating the Base with the land loss rate increased by 50 percent (Simulation LLR1) and decreased by 50 percent (Simulation LLR2). The base case land loss rate for the SAND and SAND2 models is 275 acre/y. For the Boustany model the loss is expressed as 0.55 percent of the existing land area each year. Simulation results are summarized in Table 14. Note that for all of the models, the greater the land loss rate, the greater the net (FWP-FWOP) benefits. Net benefits change by less than 3 percent for the SAND2 model and less than 10 percent for the Boustany and SAND models.

Table 14. Boustany, SAND and SAND2 Model Sensitivity to Land Loss Rate							
		Boustany		SAND		SAND2	
Sim. No.	Land Loss Rate	FWP Acres	FWP-FWOP Acres	FWP Acres	FWP-FWOP Acres	FWP Acres	FWP-FWOP Acres
Base	δ=275 ac or δ=0.55% (Bous)	66	32	68	32	72	36
LLR1	δ=412ac or δ=0.824% (Bous)	61	34	62	33	71	36
LLR2	δ=137 ac or δ=0.274% (Bous)	72	30	73	30	78	35

Nutrient Contribution. In this section the nutrient contribution to the total land benefit will be analyzed. For the Base simulation, the land acreage produced only from the nutrient contribution is 3,000 to 4,000 acres for the Boustany and SAND models and 17,000 acres for the SAND2 model. While the method for calculating the nutrient benefit is essentially the same for the Boustany and SAND models, the calculation in the SAND2 model is fundamentally different and results in much larger nutrient benefits. The nutrient benefit calculation methods are provided in the model overview section of this report. Note that the total acres created estimated by the SAND and SAND2 model are 68,000 and 72,000, respectively, for the Base simulation. The difference is only

4,000 acres, but the nutrient contribution difference is 14,000 acres. This suggests that the inorganic benefit calculation for the SAND model was on the order of 10,000 acres greater than that estimated by the SAND2 model. This difference is due to the difference in the driving hydrograph. The SAND model is forced with a single representative annual hydrograph, and the SAND2 model is driven with a 25-yr hydrograph.

The nutrient benefit in the Boustany and SAND models is essentially calculated as a reduction in the land loss rate based on the strengthening of vegetated areas from the nutrients introduced by the flow diversion. The benefit is calculated from Equations (5) – (7). The calculation of the potential land area that can be supported by the diversion loading (Equation 6) is dependent on a number of user-specified inputs. To demonstrate, sensitivity to the plant productivity rate (Pr), percent of plant biomass containing nutrients (γ_{TNP}), and percent of nutrients retained in system (R_{nut}) will be evaluated.

Several studies have been conducted and attempted to quantify the plant productivity rate. It is highly variable through the growing season and can also vary with marsh type. Based on several literature sources (e.g., Hopkinson et al. 1978; Gosselink 1984; Nyman et al. 1995; Visser and Sasser 2006; and Darby and Turner 2008), productivity rates can vary from approximately 1,000 to 13,000 g/m^2y. The value applied in the Boustany and SAND models for the Base simulation is 4,150 g/m^2y. To assess model sensitivity, this rate was halved and doubled. The percent of plant biomass containing nutrients is also subject to uncertainty and varies with marsh type. From Chabreck (1972), average values range from 0.42 to 1.63 percent with standard deviations from 0.3 to 0.6. The value used for the Base simulation is 1.25 percent. To assess model sensitivity, rates of 0.4 and 1.6 percent were simulated. The retention rate for nutrients is also subject to considerable uncertainty. Applications have typically estimated this value by dividing the land area by the total project area. The value used for the Base simulation is 40 percent. To assess model sensitivity, rates of 20 and 60 percent were simulated. Each of the nutrient inputs were varied independently, and results are summarized in Table 15. Land benefit from the nutrient contribution varies approximately 2,000 to 12,000 acres for the Boustany model and 2,000 to 10,000 acres for the SAND model.

The SAND2 model does not calculate the nutrient benefit as a reduction in the land loss rate. In this model, the nutrients are able to freely construct land which can result in significantly higher benefit estimates. The nutrients available for plant uptake are based on an approximate nitrogen budget that is developed to assess the fate of diversion loaded nitrogen. Therefore, a nutrient retention value is not specified. The calculation is dependent on a number of user-specified inputs including the plant productivity rate (Pr), percent of plant biomass containing nitrogen (γ_{TN}), and the denitrification rate (D). The sensitivity of the model to these inputs was analyzed. Consistent with the Boustany and SAND model analysis, the plant productivity rates applied as input will be halved and doubled, and the percent of plant biomass containing nutrients will be simulated at 0.4 and 1.6 percent.

Table 15. Boustany and SAND Model Sensitivity to Nutrient Inputs					
		Boustany		**SAND**	
Sim. No.	**Parameters**	$A_{nut,pot}$ **Acres (x10^3)**	**Total Nutrient Benefit Acres (x10^3)**	$A_{nut,pot}$ **Acres (x10^3)**	**Total Nutrient Benefit Acres (x10^3)**
Base	*Pr=4150 g/m^{2}y* γ_{TNP} *=1.25%* R_{nut}*=40%*	14	3.7	14	3.3
NUT1	*Pr=2075 g/m^{2}y* γ_{TNP} *=1.25%* R_{nut}*=40%*	27	7.5	27	6.4
NUT2	*Pr=8300 g/m^{2}y* γ_{TNP} *=1.25%* R_{nut}*=40%*	6.8	1.9	6.8	1.7
NUT3	*Pr=4150 g/m^{2}y* γ_{TNP} *=0.4%* R_{nut}*=40%*	42	11.6	42	9.7
NUT4	*Pr=4150 g/m^{2}y* γ_{TNP} *=1.6%* R_{nut}*=40%*	11	2.9	11	2.6
NUT5	*Pr=4150 g/m^{2}y* γ_{TNP} *=1.25%* R_{nut}*=20%*	6.8	1.9	6.8	1.7
NUT6	*Pr=4150 g/m^{2}y* γ_{TNP} *=1.25%* R_{nut}*=60%*	20	5.6	20	4.9

Denitrification is also subject to a considerable amount of uncertainty. From the literature (e.g., Gardner et al. 1993; DeLaune and Jugsujinda 2003; and Hyfield et al. 2008), values vary from 4 to 36 g/m^{2}y. The value used for the Base simulation was 21 g/m^{2}y. This value will be decreased and increased by 50 percent to assess sensitivity (10 and 32 g/m^{2}y). Each of the nutrient inputs was varied independently and results are summarized in Table 16. Land benefit from the nutrient contribution varies approximately 11,000 to 25,000 acres. The SAND2 nutrient calculation is most sensitive to the productivity rate and relatively insensitive to the denitrification rate.

The nutrient contribution analysis demonstrates that the SAND2 model produces nutrient benefits up to ten times that of the Boustany and SAND model for similar inputs. The analysis also highlights how inconsistent model results are given with changes in the plant productivity rate. The Boustany and SAND model methodology calculates the mass of nutrients required to sustain a given acre of marsh and, based on the ratio of nutrients delivered to the nutrients required, essentially reduces the land loss rate (Equations 4-7). An assumption in these calculations is that the mass of nutrients required by the wetland is the mass of nutrients held in the plant biomass. Therefore, as plant productivity increases, the mass of nitrogen required to sustain the wetland increases. These models then predict that as plant productivity increases, the land benefit from the nutrients decreases because a greater mass of nutrients is required to sustain the existing wetlands. The SAND2 model, however, calculates the mass of biomass produced by the vegetation and assumes that is the mass of organic sediments produced. Therefore, as plant productivity increases,

the land benefit from nutrients increases. This is seen from comparing results from the Base and Simulations NUT1, NUT2, NUT7, and NUT8 in Tables 15 and 16. A detailed review of the underlying assumptions of both nutrient methodologies should be conducted.

Table 16. SAND2 Model Sensitivity to Nutrient Inputs

Sim. No.	**Parameters**	**SAND2** *Total Nutrient Benefit Acres($x10^3$)*
Base	*Pr*= 3735 to 4357.5 g/m^2y γ_{TN} =1.25% D=21 g/m^2y	17
NUT7	*Pr*= 1868 to 2179 g/m^2y γ_{TN} =1.25% D=21 g/m^2y	11
NUT8	*Pr*= 7470 to 8715 g/m^2y γ_{TN} =1.25% D=21 g/m^2y	25
NUT9	*Pr*= 3735 to 4357.5 g/m^2y γ_{TN} =0.4% D=21 g/m^2y	23
NUT10	*Pr*= 3735 to 4357.5 g/m^2y γ_{TN} =1.6% D=21 g/m^2y	16
NUT11	*Pr*= 3735 to 4357.5 g/m^2y γ_{TN} =1.25% D=10 g/m^2y	19
NUT12	*Pr*= 3735 to 4357.5 g/m^2y γ_{TN} =1.25% D=32 g/m^2y	17

Sea Level Rise Considerations. RSLR can be accounted for in the models through the background land loss rate and specified depth of the receiving area. As previously discussed, the depth of the receiving basin is a key input parameter and one to which the calculation of benefits is sensitive. To appropriately consider the impact of RSLR, the depth of the receiving basin in Equations 2 and 14 should be increased at the rate of sea level rise. The inter-annual variability in basin water depth is accounted for in the SAND2 model framework, and the sensitivity of the model to this was assessed by making some modifications to the program to increase the water depth by the estimated historic sea level rise rate of 0.4 in. per year. Considering sea level rise, the net benefit (FWP-FWOP) decreased from 36,000 acres for the Base simulation to 31,000 acres, a 15 percent decrease.

CONCLUSIONS: The sensitivity of the Boustany, SAND, and SAND2 models to various parameters and inputs has been analyzed. Table 17 provides a summary of the percent change in the calculated FWP acres and net benefit (FWP-FWOP) for the change in input variables evaluated in this CHETN. The input variables were varied over a reasonable range of values, and the range of percent change in calculated benefit is reported in Table 17. The values in Table 17 indicate that the models are most sensitive to bulk density, the consideration of marsh elevation, water depth of the receiving basin, and various nutrient parameters. The values in Table 17 isolated the sensitivity of various parameters, but several of the parameters are not independent. For example, the

specification of the project area can affect the depth of the receiving basin which influences the estimate of bulk density of the receiving wetland. The inter-dependency of many parameters should be recognized in practice.

Table 17. Boustany, SAND and SAND2 Model Sensitivity Summary

	Boustany		SAND		SAND2	
Parameter	**% Change FWP Acres**	**% Change FWP-FWOP Acres**	**% Change FWP Acres**	**% Change FWP-FWOP Acres**	**% Change FWP Acres**	**% Change FWP-FWOP Acres**
Sediment Rating Curve	NA	NA	-7	-12	-2	-3
Grain Size Distribution	NA	NA	+/-10	-25 to +19	+/-6	+/-11
Bulk Density	-22 to -30	-53 to -69	-24 to -30	-53 to -69	-28 to -38	-56 to -75
Marsh Elevation of 1 ft	-12	-44	-19	-44	-22	-44
Water Depth	-20	-44	-22	-44	-24	-47
Smaller Project Area	-2	-3	-3	-6	-10	-20
Land Loss Rate	-8 to +9	+/-6	-8 to +7	-6 to +3	-1 to +8	-3 to 0
SLR Adjustment	NA	NA	NA	NA	-9	-15
Nutrient Parameters:	**% Change Total Nutrient Benefit Acres**		**% Change Total Nutrient Benefit Acres**		**% Change Total Nutrient Benefit Acres**	
Plant Productivity	-49 to +103		-48 to +94		-35 to +47	
Percent of Biomass Containing Nutrients	-22 to +214		-21 to +194		-6 to +35	
Percent of Nutrients Retained in System	-49 to +51		+/-48		NA	
Denitrification Rate	NA		NA		0 to +12	

The nutrient calculations in all of the models are sensitive to selection of input parameters. The nutrient benefit from the Boustany and SAND is lower than that for the SAND2 model, and, therefore, the percent changes reported in Table 17 can be much greater. All the models are sensitive to the plant productivity and the percent of biomass containing nutrients. In addition to the sensitivity of the calculations to input parameters, other concerns with the nutrient calculations are as follows:

- There is a large discrepancy in the calculated nutrient benefit between the SAND2 and other models. The calculated SAND2 nutrient benefit is five times that of the Boustany and SAND models.
- The sensitivity to plant productivity is inconsistent between the Boustany/SAND models and the SAND2 model.
- The formulation for the SAND2 model may be over-estimating the organic contribution to land building. Note from Equation 2 that the volume of inorganic sediment is divided by the bulk density of the receiving area wetland. The bulk densities used are those of wetland soils that have an organic sediment fraction included. The SAND2 model introduces a mass of organic sediment produced and, in Equation 14, divides that by a wetland soil bulk density and depth to get an area of land created. The bulk densities of wetland soils are less

than 1, and this creates a multiplier on the organic sediment contribution. The theoretical foundation of the SAND2 nutrient calculation needs to be thoroughly reviewed by a wetland expert.

The sensitivity of the models requires careful application and consideration of all input parameters. All applications should present a range of possible outcomes given the uncertainty associated with many of the key parameters. Ideally, a life-cycle analysis should be conducted that considers multiple futures and a comprehensive range of input parameters.

ADDITIONAL INFORMATION: For additional information, contact Ty V. Wamsley, Coastal and Hydraulics Laboratory, U.S. Army Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180, at 601-634-3249, or e-mail: *Ty.V.Wamsley@usace.army.mil*. This CHETN should be cited as follows:

> Wamsley, T. V. 2011. *Land building models: Uncertainty in and sensitivity to key input parameters*. ERDC/CHL CHETN-VI-44. Vicksburg, MS: US Army Engineer Research and Development Center.

An electronic copy of this CHETN is available from *http://chl.erdc.usace.army.mil/chetn*.

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